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From data to solutions • Subsurface Evaluations • Laboratory Services • Recruitment Services

Adding value to routinely obtained geothermal well data

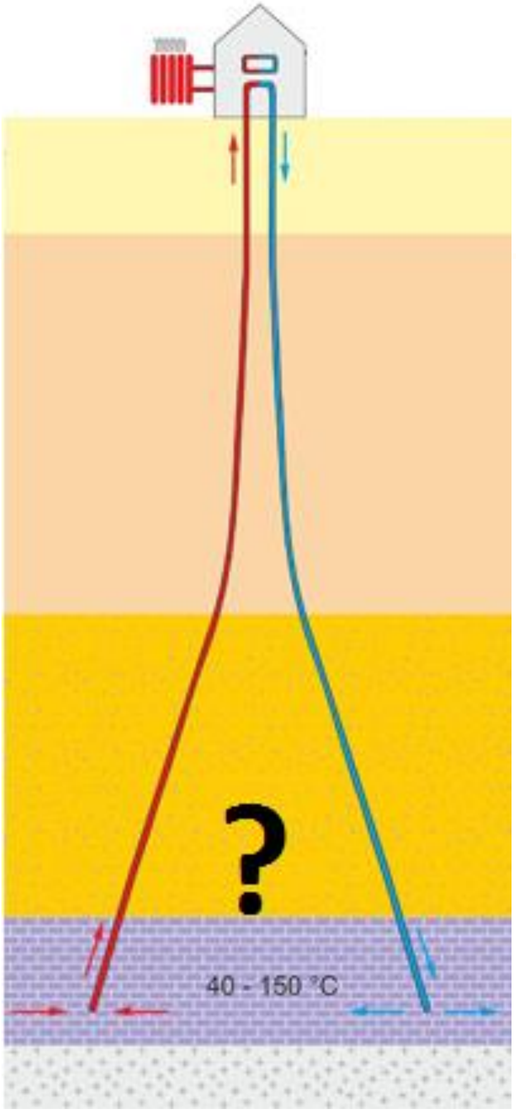
08 March 2018

Introduction

Why this study?

- Increasing number of geothermal wells. However only a limited amount of data is collected in the drilling phase (financial limitations).

- This data is not always used to its full extent. Further analysing this data could aid in a better understanding of the subsurface without adding significant costs.



Overview

1. Review existing data: What datatypes are routinely obtained from geothermal wells?

2. Additional information

   What information can we obtain extra from the routinely obtained data?

3. Data integration

4. Conclusions and recommendations

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1: Routinely obtained data

- 27 End of Well (EOW) reports from geothermal wells were reviewed. Various types of data was gathered from the:
  - Rock type (cuttings, GR)
  - Rock strength (LOT, Caliper, ROP)
  - Hydrocarbons (HC gas log)
  - Drilling mud (Type, Weight)
  - Well cementation (CBL, rate)
  - Drilling data (WOB, RPM)

How can all this data be of further use to the operators?

1: Routinely obtained data

- 27 End of Well (EOW) reports from geothermal wells were reviewed. Various types of data was gathered from the:
  - Rock type
  - Rock strength

Valuable information

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2: Additional information

- Additional information on the rock (type and strength) can be obtained from:
  - Drill cuttings
  - Drilling parameters
  - Log data
  - Well tests

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2: Additional information

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2: What are drill cuttings

- Very valuable for further analysis are drill cuttings:
  - Cuttings are fragments of rock derived from the penetrated formation.
  - They are circulated out of the borehole and gathered in shakers at surface.
  - Cuttings are interpreted for lithology.
    This is the only direct lithology information.

- Cuttings are briefly described onsite and reported for all studied wells. No further analysis is done on cuttings.

- Disadvantage: Cuttings can only be related to a depth interval, not an exact depth.

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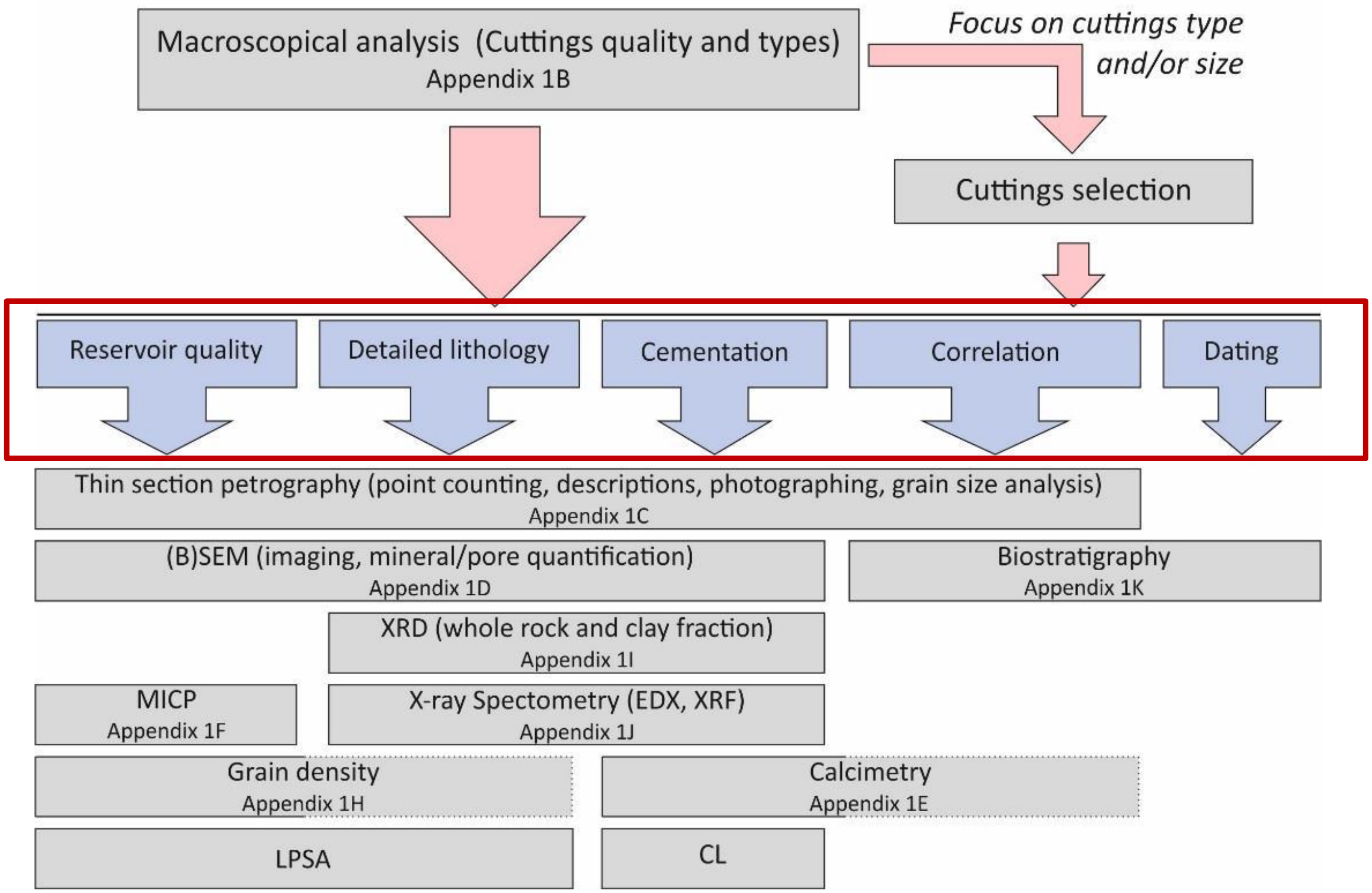
2: Drill cuttings analysis methods

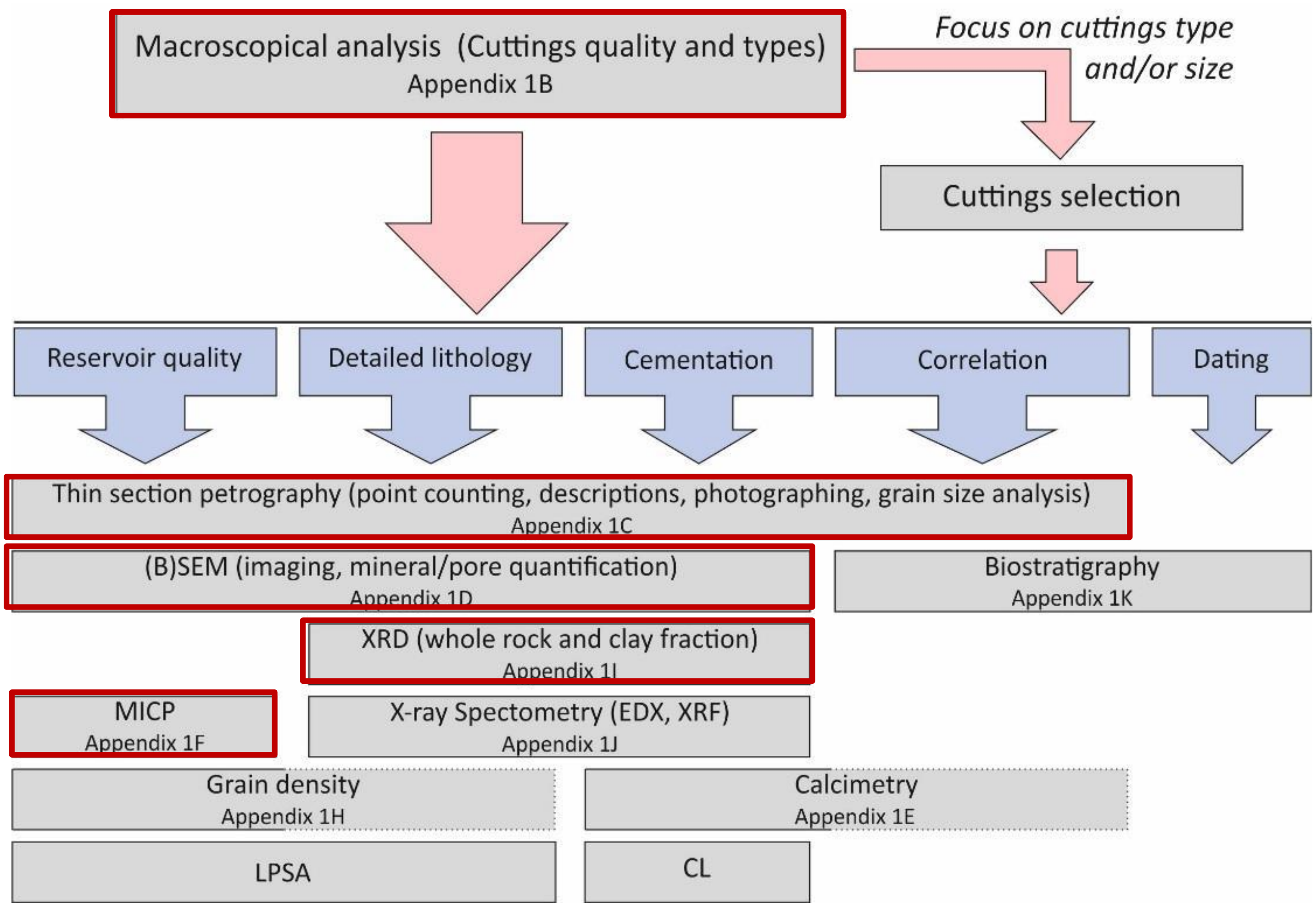
- What analyses can be done on cuttings to get more information?

Analysis	Type of analysis	Information obtained	Why useful
Macroscopic Analysis	Macroscale analysis	Cuttings quality, lithology	Stratigraphy, reservoir quality
Thin Section Petrography	Microscale analysis	Cuttings qulaity, detailed lithology, porosity	Stratigraphy, reservoir quality
Scanning Electron Microscope (BSEM & SEM)	Microscale analysis	Detailed lithology, porosity, clay mineralogy	Detailed info on reservoir quality
Calcimetry	Bulk rock analysis	Carbonate cement quantification	Reservoir quality related to diagenesis
Mercury Injection Capillary Pressure (MICP)	Reservoir quality analysis	Pore throat size distribution	Direct measure of reservoir quality
Laser Particle Size Analysis (LPSA)	Bulk rock analysis	Grain size distribution, clay content	Indirect measure of reservoir quality
Grain Density Analysis	Bulk rock analysis	Identification of high density intervals	Indirect measure of reservoir quality
X-ray Diffraction (XRD)	Bulk rock analysis	Mineral composition, clay mineralogy	Indirect measure of reservoir quality
X-ray Spectometry (EDX, XRF)	Bulk rock analysis	Elemental composition to identify minerals	Indirect measure of reservoir quality
Biostratigraphy	Microscale analysis	Microfossil content and distribution	Dating, correlation

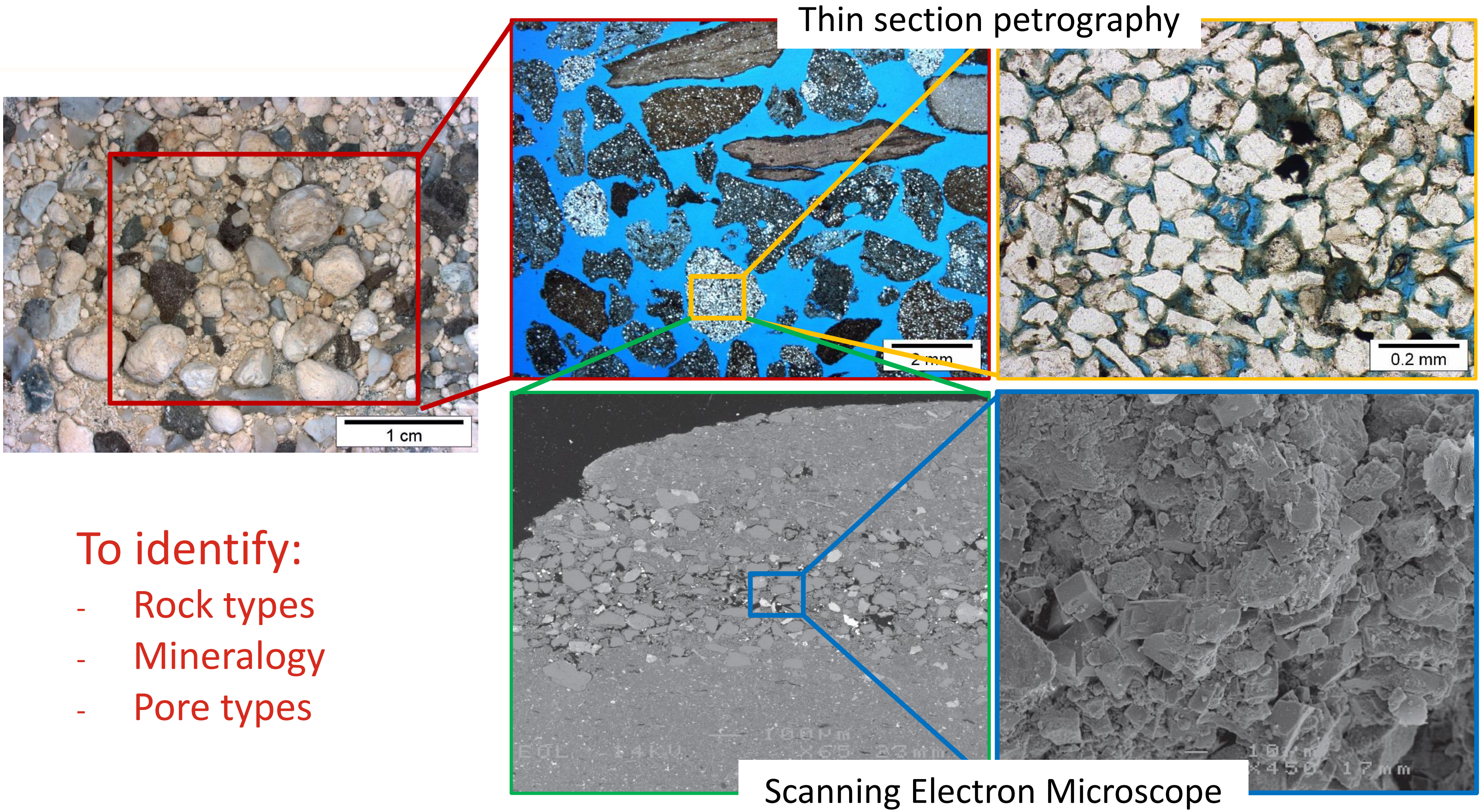
2: What information can be obtained from drill cuttings?



2: What information can be obtained from drill cuttings?



2: Optical analyses on drill cuttings



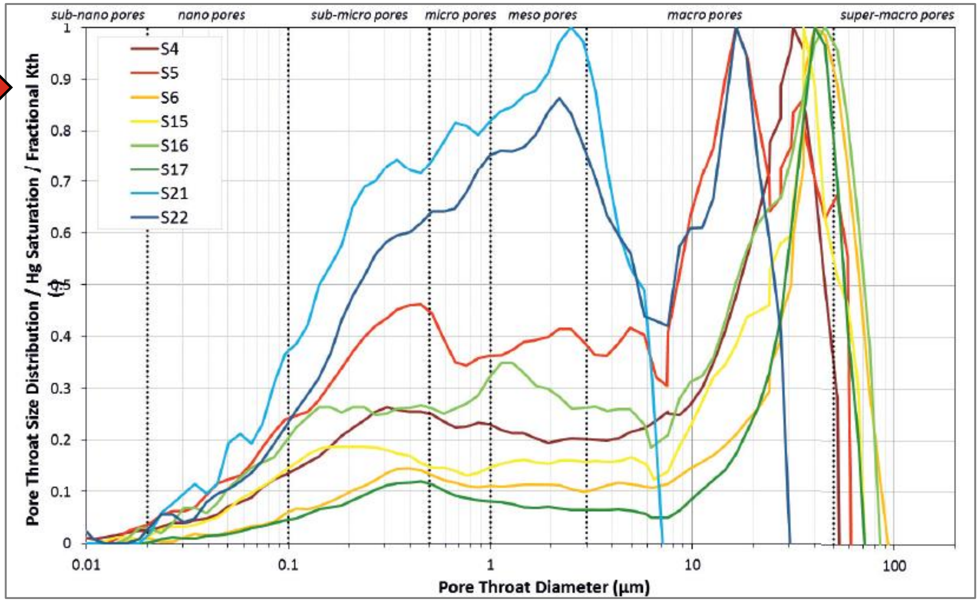
To identify:

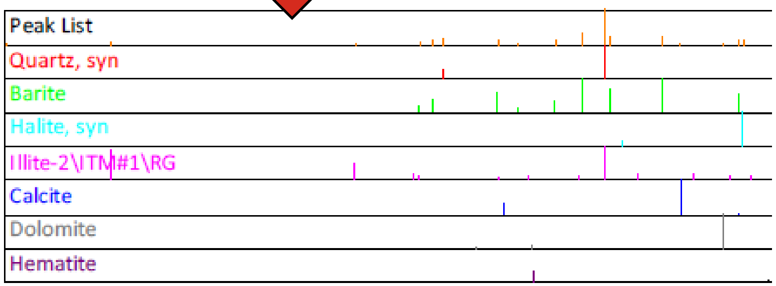
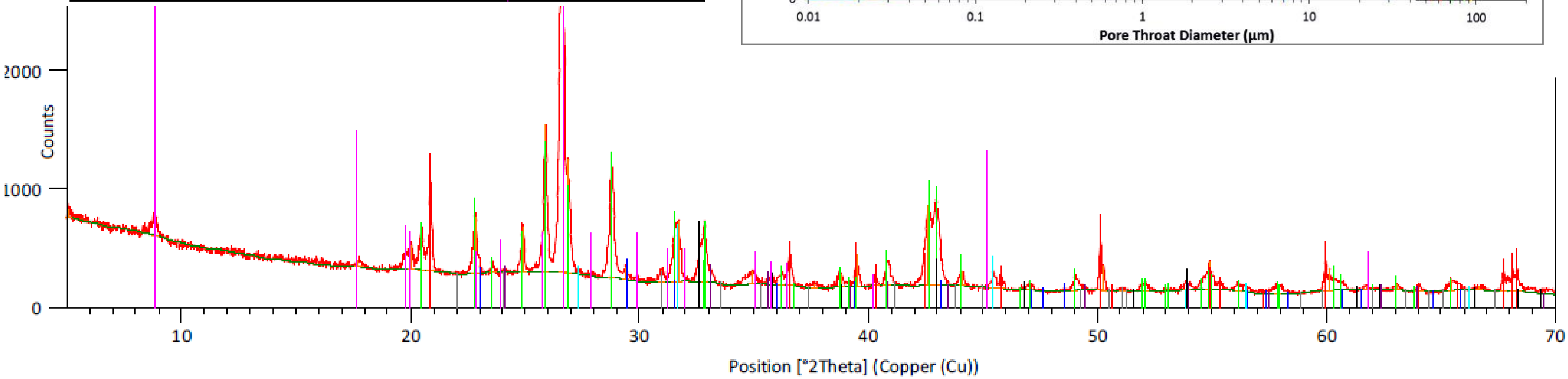
- Rock types
- Mineralogy
- Pore types

2: Analytical techniques on drill cuttings

To determine:

- Pore throat diameter (MICP)
- Minerals and clay types (XRD)



2: What can we do with this information?

- With optical analyses and XRD, the reservoir permeability can be better understood as described by type of cement and porosity indications.
  - The mineralogy is important to optimise drilling mud composition and stimulation fluids to minimise the risk of formation damage.

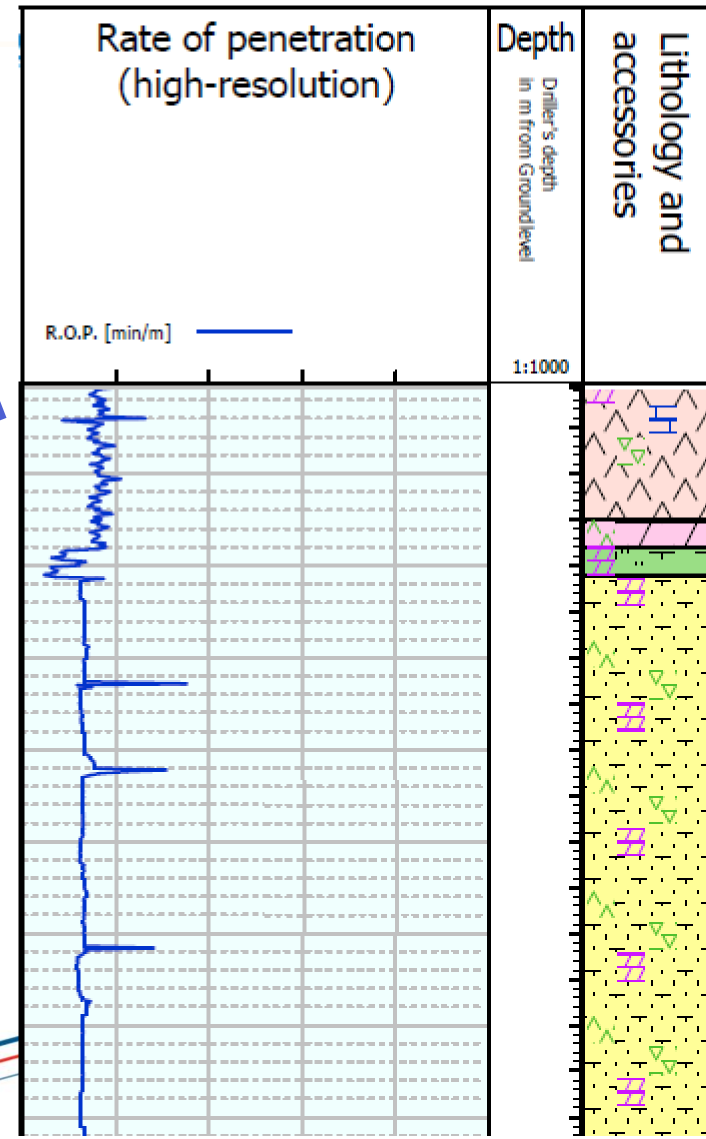
- With MICP, an estimate of the reservoir permeability can be determined.
  - The pore throat diameter is important to optimise drilling mud particle design (drilling particles > 1/3 pore throat) and avoid formation damage.

2: Additional information

- Additional information on the rock (type and strength) can be obtained from:
  - Drill cuttings
  - Drilling parameters
  - Log data
  - Well tests

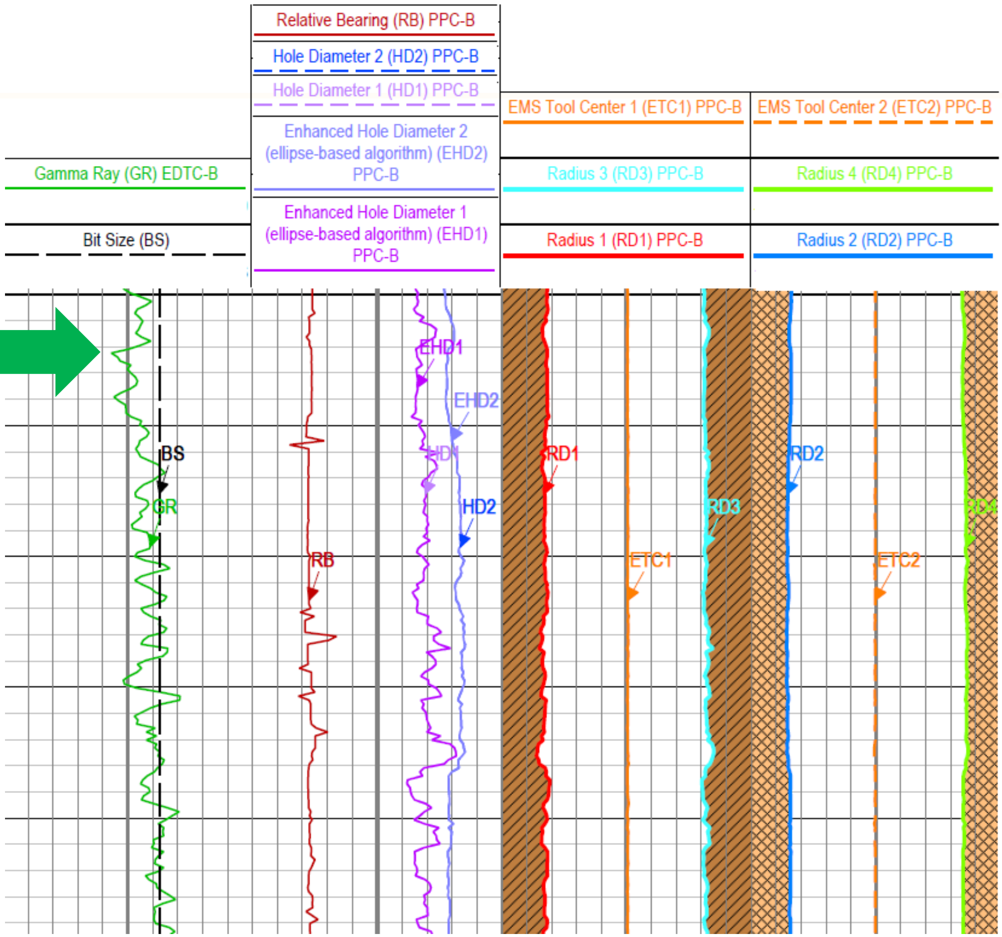
2: Information from drilling parameters

- What information on the rocks can be obtained from drilling parameters?
  - Regularly recorded drilling parameters are strength tests (FIT / FST / LOT), the rate of penetration (ROP) and mud losses.
  - The ROP gives an indication of lithology and porosity/permeability.
  - The strength tests give information on Fracture Initiation Pressure, important for limiting Injection Pressures.
  - Together with cuttings analysis and log data, the data can be used to better characterise the lithology (strength), identify lithology transitions and identify fractures or karsts.



2: Information from log data

- What information on the rocks can be obtained from well logs?
  - Gamma Ray (GR) Logs are used to determine the lithology (e.g. sand vs. shale) and to calibrate depth.
  - Calcimetry / dolomitry logs are used to determine the carbonate content. This can be used together and calibrated with cuttings analyses.
  - Other logs such as the CBL, the Gas Log and the Caliper Log do not provide significant additional information to the lithology.



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2: Additional information

- Additional information on the rock (type and strength) can be obtained from:
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2: Information from well tests

- The main information (geothermal) well tests provide is the transmissibility, skin factor and production index.
  - The transmissibility (permeability x thickness) provides info on the reservoir quality.
  - The skin factor provides information on the production efficiency.
- Well tests provide information on flow barriers and well connectivity.

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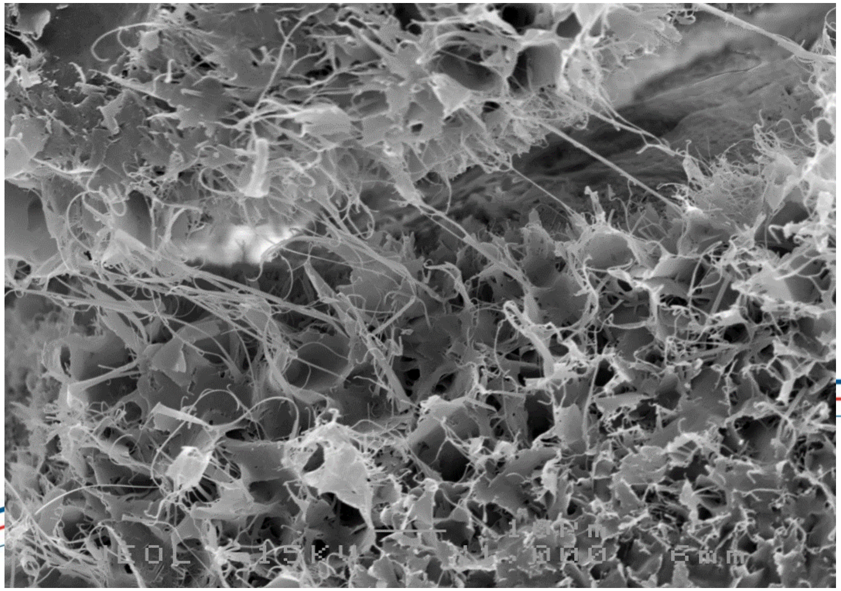
3: Data integration

How does the integration aid in answering questions that arise during drilling and production?

- Reasons for drilling problems can be complex:
  - Swelling clays, cementation streaks, salt intervals, fractures, etc. could all contribute to drilling problems.
  - The cause can be identified with by combining e.g. cuttings data, logs, drilling parameters.

Knowing the cause of the problem aids in the finding a good solution, also for future projects.

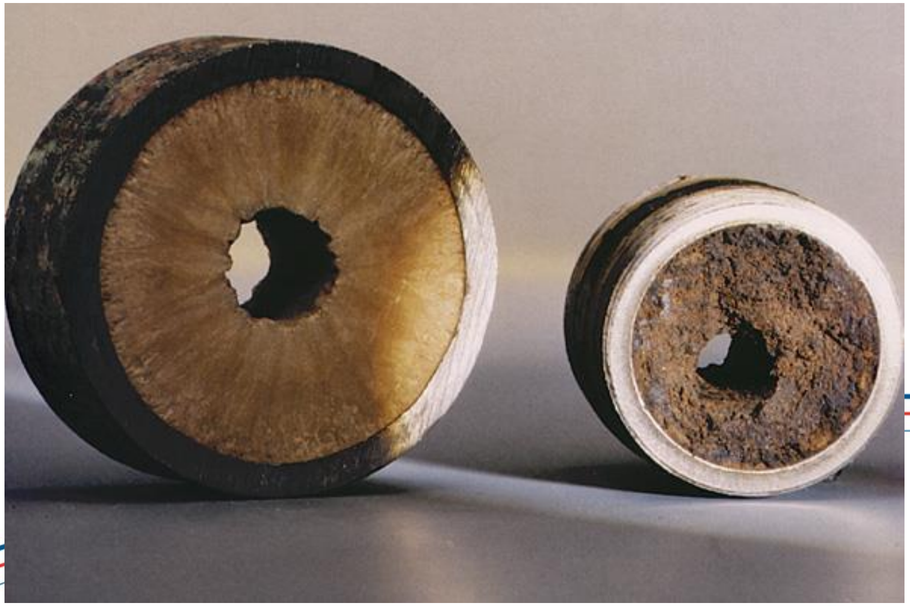


3: Data integration

How does the integration aid in answering questions that arise during drilling and production?

- Reasons for production problems can be numerous:
  - There can be fines production (formation material?), scaling and corrosion, etc.
  - The cause can be identified by sampling the material and performing e.g. XRD, EDX and acid tests.

Knowing the cause of the problem aids in the finding a good solution, also for future projects.



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Potentially important information can be gathered from routinely obtained data.

- Most promising are drill cuttings, which provide the only direct information of the rock.
  - A variation of analyses can be performed on cuttings, in order to get more knowledge on the reservoir type and quality, or answer questions to specific problems.

- Log data and drilling parameters are relatively rare thus not always available for geothermal wells.

4: Conclusions and recommendations

- It is important to get more information to guide future projects in the area.
  - E.g. by obtaining more log data, such as porosity logs.
- Standardize the geothermal wells reporting strategy to get a uniform knowledge database.
  - This includes e.g. composite logs, well reports.
  - Store cuttings samples in a central location in order to quickly perform additional analysis if required.

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Thank you!

Routinely obtained data

DATA TYPE → / WELL ↓	ROCK TYPE				ROCK STRENGTH / FRACTURES					HYDROCARBONS		MUD		WELL CEMENTATION		DRILLING			DATA TYPE ← / WELL ↓
	Cuttings: Lithology	Cuttings: Lithological Accessories	Cuttings: Calcimetry and Dolometry	Log: GR (Gamma Ray)	LOT (Leak-off Test)	FIT/FST (Formation Integrity/ Strength Test)	Log: Caliper	ROP (Rate of Penetration)	Mud Loss / Lost Circulation	Log: HC Gas	Water/Gas analysis	Mud Weight	Mud type	CBL (Cement Bond Log)	Cement pump rate vs Pressure (CJR - Cement Job Report)	String Weight (WOB & Hookload)	RPM	Torque	
1	x	x		X, Partly		x	X, Partly	x		x		x	x	x	x	x	x	x	1
2	x	x		X, Partly		x	X, Partly	x		x		x	x	x	x	x			2
3	x	x		X, Partly		x	X, Partly	x		x		x	x	x		x			3
4	x	x		X, Partly		x	X, Partly	x		x		x	x	x	x	x			4
5	x	x		X, Partly			X, Partly	x		x	x		x		x	x			5
6	x	x		X, Partly				x		x			x		x	x			6
7	X (Described, litholog not at TNO)												x		x				7
8	x	x	X, Partly	x				x		x			x						8
9	x	x		x				x		x			x						9
10	x	x		x				x		x		x	x			x			10
11	x	x		x				x		X, Partly			x			x			11
12	x		x	x				x		X, Partly			x						12
13	x		x	x				x		X, Partly			x						13
14	X (In technical log, litholog not at TNO)							X (In technical log, litholog not at TNO)					x			x	x	x	14
15	x	x		x				x		X, Partly			x			x			15
16	x			X, Partly				X, Partly		x		x	x			X, Partly, only WOB			16
17	x			X, Partly				x		x		x	x			X, only WOB			17
18	x	X - paleontology	X, Partly	X, Partly	x	x		x		X, Partly		x	x	x	x	x			18
19	x	X - paleontology	X, Partly	X, Partly	x	x		X, Partly		X, Partly		x	x	x	x	X, Partly			19
20	x	x						X, Partly		X, Partly		x	x	x		X, only Hookload			20
21	x	x						x	x	x		x	x	x		x			21
22	x	x						X, Partly		X, Partly		x	x	X, Not at TNO		X, Partly			22
23	x	x		X, Partly				X, Partly		X, Partly		x	x	X, Not at TNO		X, Partly			23
24	x	x		x			X, Partly	x		X, >60m		x	x			x			24
25	x	x		X, Partly			X, Partly	x		x		x	x	x		x			25
26	x	x		x			X, Partly	x	x	x		x	x	x		x			26
27	x	x		x			X, Partly	x		X, Partly		x	x	x		x			27
Total	27	21	5	22	2	6	9	26	2	25	1	17	27	13	8	22	2	2	Total

Table 1: Overview table showing the available data gathered from end-of-well (EOW) reports of 27 geothermal wells from 10 areas in The Netherlands.

Additional information

What are cuttings?

Drill cuttings are broken bits of the penetrated rock that are transported by the mudstream from the bit to the surface during drilling. The difference between the depth the cuttings are assumed to originate from, and the wireline depth, is corrected with the GR log.

Cuttings brought to the surface are commonly directly described. After first description, the cuttings (both a washed and unwashed fraction) should be stored for potential future analyses.

Cuttings provide the only physical information of the lithology that is penetrated during drilling. Several relevant quantitative analyses can be performed on the cuttings to get information on lithology, mineral composition of the reservoir rock and reservoir quality.

The size and quality of cuttings depend strongly on the rock formation, the drill bit used, the rate of penetration and the pressure applied to the drill bit.

It has to be noted that cuttings are an average representation of the rocks over the sampled interval (commonly m-scale). These intervals commonly vary along the well.

Common sampling interval is 2m per sample (= ~100 samples for a ~200m interval).

Risks & Uncertainties

The drill bit type strongly affects the cutting quality. PDC bits alter the cuttings whereas roller cone bits potential create good quality cuttings. During the first cuttings analysis, an inspection of the cuttings quality should be done.

Drilling mud contaminates the drill cuttings. Therefore, it is important to know the drilling mud type (OBM vs WBM) as the mud composition influences the analytical results. Also mud additives need to be identified and separated from the rock material.

Cavings (i.e. loose material, commonly shale, that falls into the wellbore) pose a different problem, as these imply that certain rock types are present whereas these are actually derived from formations above. Potential cavings problems can be identified and accounted for in the caliper log.

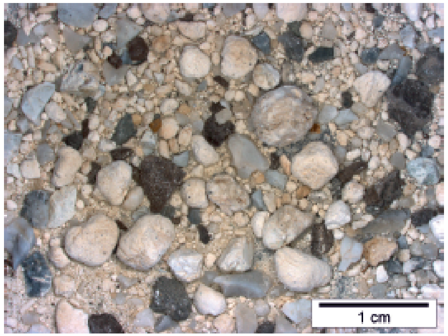
As cuttings cover a certain depth range, the uncertanties in lithology and lithological variations are relatively large. Therefore, the results from analytical analyses performed on cuttings should be considered as semi-quantitative.

Analyses

The following analyses can be performed on cuttings:

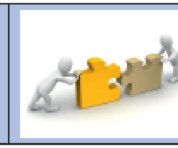
- Detailed Macroscopic Description
- Thin Section Petrography
- Scanning Electron Microscopy ((B)SEM)
- X-ray Diffraction Analysis (XRD)
- X-ray Spectrometry (EDX, XRF)
- Biostratigraphy
- Calcimetry
- Grain Density Analysis
- Mercury Injection Capillary Pressure analyses (MICP)
- Laser Particle Size Analysis (LPSA)

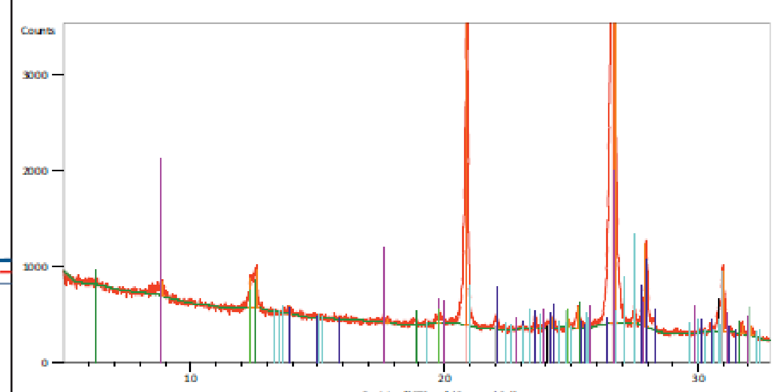
Each type of analysis is discussed on separate pages. The purpose of each analysis is summarised in Table 2 of the report.



Additional information

Appendix 1I — Type of Analysis: X-ray Diffraction (XRD)

 How? Technical details	 Why? Benefits	 Limitations	 Price estimate	 To combine with...
Whole Rock and Clay Fraction X-ray diffraction (XRD) analysis can be done on rock samples. Whole Rock (WR) measures the bulk rock composition. Clay Fraction (CF) measures the clay-sized particle composition (<2µm). In an XRD-instrument, X-rays are bombarding the sample. Each mineral in the sample diffracts the X-rays differently. The resulting diffractograms allows for identification of the crystalline phases. A semiquantitative calculation of the composition can be done based on the relative heigth and width of the mineral specific peaks.	WR XRD analysis is done to determine mineralogy in order to identify the composition (presence of stable minerals) of the siliciclastic or carbonate rock. Also the presence of potentially porosity reducing cements can be identified. CF XRD analyses is done to determine the clay mineralogy, including the swelling clays. Clay minerals generally affect the reservoir quality significantly, also in small quantities. A combination of WR and CF analyses gives the full-range (from clay, to cements to quartz grains etc.) insights in the mineralogy.	Limitations are mostly related to mud additives and drill mud composition, which influence the results. The sample must therefore be cleaned properly prior to analysis, with understanding of the drilling mud used. No information on the non-crystalline material can be obtained. If non-crystalline material is present (e.g. organics, mud additives), the noise/background data will increase.	Per sample: • WR analysis, ~200€ • WR+CF analysis, ~425€ Per interval: Depends on the sampling interval and frequency from the formation of interest as well as the sample quality (does it requires additional sample preparation /cleaning?).	XRD can best be combined with: • TS petrography to check the spatial distribution of cements and clay minerals. • XRF and EDX to check with the elemental composition, confirming mineral composition and/or non-crystalline material occurrence.



Data Integration

Question?	Solution	Suggested analyses
1: How do I determine whether swelling clays are present?	Swelling clays are directly identified by clay fraction XRD analysis on cuttings. SEM analysis on clays can also identify potential swelling clays from non-swelling clays. During drilling, the mud composition can be adapted to inhibit swelling (e.g. by increasing salinity). To check the effects of salinity on the clays, a swelling test can be done.	• Hot-shot Clay Fraction XRD analysis (i.e. analysis can be done during or directly after drilling to remedy drilling problems) • SEM analysis • Cuttings swelling test
2: How do I determine the reason for drilling problems?	Some of the most common drilling problems are pipe sticking, lost circulation and borehole instability. These problems can be very complex and related to (a combination of) e.g. hole deviation, the mud, cuttings accumulation in the annular space. This in turn could be related to the rock lithology, variations in lithology, rock strength etc. In case a lithologic problem is expected cuttings analysis may help in the understanding of the problem. For example, are drilling problems likely to be due to shaly intervals, swelling clays, salt intervals, carbonate-rich intervals or fractured intervals?	• Shales: WR & CF XRD, SEM • Carbonates: WR XRD, SEM, TS Petrography, Calcimetry • Salt: GR log, WR XRD, SEM • Fractures: See question 5.
3: How do I analyse (unexpected) cementation streaks?	Cementation streaks are intervals of varying thickness (few cm to a few m) enriched in e.g. carbonate, anhydrite or salt cement where the permeability is (strongly) reduced. The presence of cemented layers can sometimes be related to the original depositional environment of the sediment, although often it has a post-depositional origin. Cement streaks can be identified by analysing the GR log in combination with thin section petrography, SEM, EDX/XRF and XRD on cuttings which allows for identifying the cementing mineral as well as the structure/pervasiveness of the cement. In the case of carbonate cement, the cement content and type can also be analysed with an acid solubility test.	• GR log • Thin section petrography on cuttings • BSEM analyses • EDX • XRD/XRF • Acid solubility test / Calcimetry